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Solar energy potential for sustainable development in Afghanistan

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Abstract
Afghanistan's energy generation deficiency relies heavily on fossil fuels and imported electricity. The country is experiencing rapid population growth and advances in various sectors, which means that current energy sources cannot cover the country's needs. At the same time, there is a massive gap between electricity supply and demand, leading to a shortage of energy in Afghanistan. Therefore, it is necessary to develop power generation, focusing on solar energy, to ensure energy sustainability. This literature review looks at Afghanistan's potential for solar energy and identifies obstacles and challenges like security, economics, and technology. This research focuses on PV power technology and offers recommended solutions based on surveys conducted by national and international organizations. Solar power could be a good solution for the energy shortage in Afghanistan. It is theoretically, practically, and economically suitable for the country.

1. INTRODUCTION

Energy is critical to any country's socio-economic development. The majority of human activities are directly related to sustainably meeting energy demands. Afghanistan is the world's least developed country, having endured decades of war and insecurity. One of the consequences of Afghanistan's long-term war and conflict was the destruction of infrastructure, particularly energy infrastructure [1].

Afghanistan requires more energy to maintain a sustainable life cycle due to rapid population growth and industrial development. However, a severe energy supply shortage created an energy crisis in the country [2]. There is a significant gap between electricity demand and supply, most noticeable during the winter and summer seasons.

Providing electricity is no longer a permanent fixture in Afghanistan, and power outages are common, resulting in power outages lasting from hours to days [3]. Energy scarcity and prolonged outages have harmed Afghans' quality of life and stifled the country's economic development [4]. Industry, energy generation, and agriculture have been particularly vulnerable to power shortages, accounting for most financial losses over the last decade [5].

Afghanistan generates approximately one-quarter of its electricity from domestic renewable and nonrenewable sources and imports nearly one gigawatt (GW) from neighbors in particular Uzbekistan, Tajikistan, Turkmenistan, and Iran; however, the country's demanded energy for cooking and heating is primarily based on wood, charcoal, and fossil fuels [6,7].

Furthermore, Afghanistan's reliance on fossil fuels and hazardous biomass energy sources such as coal and wood has increased various environmental problems, as these sources are among the country's leading sources of air pollution [8]. Afghanistan should focus on renewable energies to deal with an energy shortage, reduce environmental hazards and the effects of climate change, and achieve economic development. Renewable energy sources are environmentally friendly, economically justifiable, and clean, and they can play an essential role in reducing carbon emissions and ensuring Afghanistan's energy security. Solar energy has the most significant potential among available renewable energy sources to address energy shortages and ensure energy sustainability in Afghanistan.

2. SOLAR ENERGY POTENTIAL IN AFGHANISTAN

Solar energy is a renewable energy that harnesses the sun's light and heat to generate electrical or thermal energy. It is a clean and cheap energy source available almost anywhere in the world. Solar energy has traditionally been used for water heating in Afghanistan. Rooftop photovoltaic (PV) was used to provide electricity to rural communities in Bamian province for the first time in 2005 [9]. PV and solar thermal technologies are now available in Afghanistan and play an essential role in providing electricity to rural communities. Solar thermal energy is primarily used in applications such as solar stoves, solar dryers, and solar water heaters in the country, in addition to generating electricity.

2.1. Theoretical solar PV potential

The utilization of solar energy yield is related to the distribution of the solar resource in areas where power generation is possible. According to the National Renewable Energy Laboratory's (NREL) theoretical Assessment of Afghanistan territory, the country is in the sunbelt, with 300 days of sunshine per year and abundant solar energy [10]. The Direct Normal Irradiance (DNI) in Afghanistan ranges from 3.38 to 7 kWh per m2, and the Global Horizontal Irradiance (GHI) is estimated to be 4.0 to 6.0 kWh per m2 per day [11]. It suggests that every 10 m2 of land in the country can generate 1 kW of solar energy, specifically through solar PV technology [12]. Higher values are found in Helmand, Kandahar, Herat, Farah, and other southern and western provinces. (Figure 1).

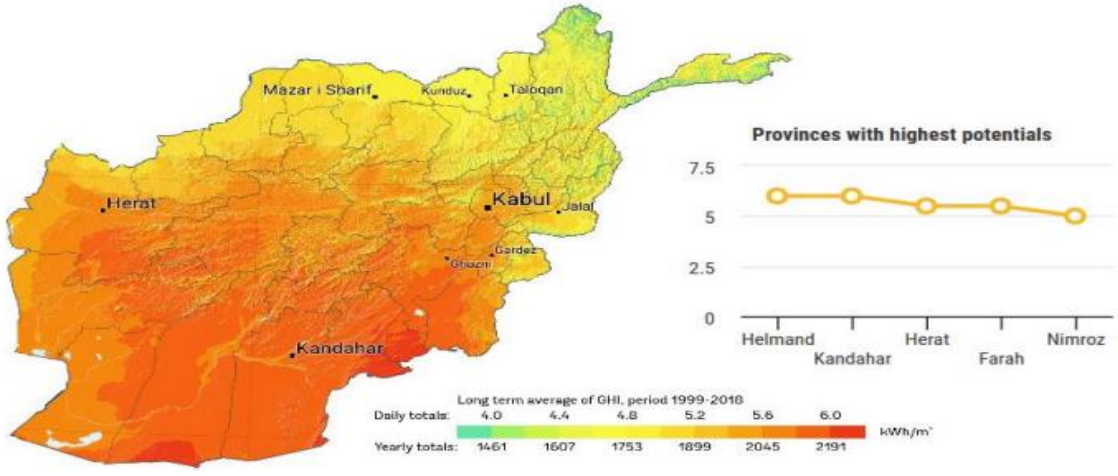
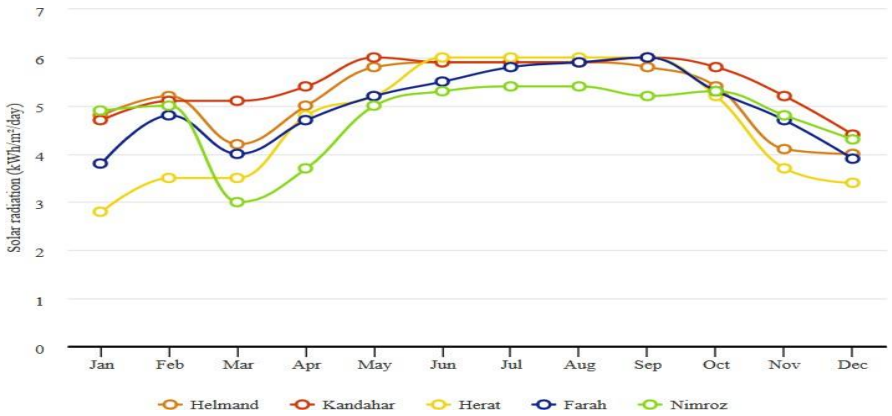


Figure.1. GHI Map of Afghanistan’sregions with the highest values of solarpotentials

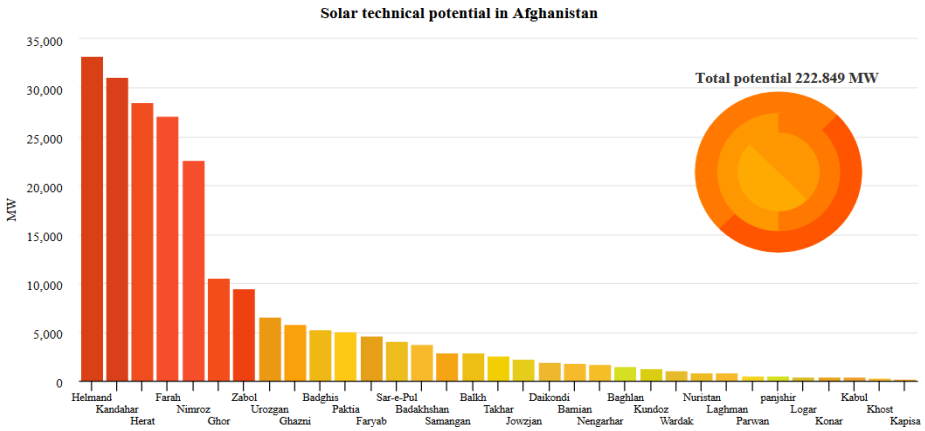
ConsideringAfghanistan's continental climate, the highest value of GHI is available from April to



October, when maximum power generation is possible. From April to October, the average GHI in the five provinces with the highest values is nearly 6.2 kWh per m2 per day, while it drops to 3.7 kWh per m2 per day the rest of the year.(Figure 2).

Figure.2. Afghanistan's provinces with the highest Monthly GHI

According to the solar radiation in regions, Afghanistan's total solar energy potential is estimated at



222,849 MW [13]. Helmand province has the highest solar energy capacity in the country, with an estimated 33,282 MW, whereas Kapisa in the north has the lowest power, with 183 MW [26]. (Figure. 3)

Figure.3. Afghanistan's provinces with the highest solar potentials

2.2. Practical solar PV potential

Currently, PV technology is the most suitable method of converting solar radiation into electricity. The PV system can achieve practical PV utilization and power output. PV power plants are now available in almost every country and are rapidly becoming the world's dominant source of electricity generation. Factors such as air temperature, terrain elevation, latitude, clouds, and shading heavily influence the suitability and efficiency of PV potential and conversion.

Afghanistan's long-term annual average temperature ranges between 12 and 14°C. The figures reach 18 degrees Celsius in the southern and western zones, 16 to 18°C in the eastern, 10 to 12°C in the northern, and 6-8°C in the central provinces, indicating that the country's air temperature is suitable for PV utilization [14]. Furthermore, Afghanistan's high solar radiation, topography, and clear sky with limited cloud availability make it an ideal location for solar PV installation. Despite some seasonal fluctuations, the average seasonality index in the country is less than 2.0, and PVOUT exceeds 4 kWh. Solar PV has the most incredible capacity to meet a significant portion of Afghanistan's current and future energy demand.

Afghanistan currently generates approximately 40 MW of electricity through solar power plants [15]. The first solar power plant, with a capacity of 1,03 MW, was built with the assistance of the New Zealand government in Bamyan province, followed by a solar PV and wind hybrid in Herat with a capacity of 2 MW and a solar plant in Kandahar with a total of 30 MW [16].

2.3. Economic viability of solar PVpotential

The economic viability of a PV installation is mainly determined by comparing the costs of producing a unit of energy from PV sources to those of other energy generation sources. This includes costs for PV panels and technology, pay-out, total capital investment, operation and maintenance costs, environmental effects, and PV's ability to compete with other forms of energy. In 2019, India and China had the lowest cost for installing PV because they are the manufacturing hubs for this system and have low installation and maintenance costs.

There are several methods for determining the economic potential of a PV system, but one of the most practical is the Levelized Cost of Electricity (LCOE) [17]. The LCOE can be used to compare different power generation technologies, both renewable and nonrenewable. The LCOE value of solar PV in a specific country can be calculated by defining LCOE and summing PVOUT using the IRENA suggested equation below.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{CAPEXt+OPEXt}{(1+d)^t}}{\sum_{t=1}^{n} \frac{PVOUTt}{(1+d)^t}} \quad (1)$$

In which;

LCOE = The average lifetime Levelized cost of electricity generation

CAPEX = Investment expenditures in the year t

OPEX = Operations and maintenance costs in the year t

PVOUTt = Electricity generation in the year t

d = Discount rate

n = Lifetime of the PV system in years

Based on the available data from IRENA and the Afghanistan Ministry of Energy and Water (MEW) and research in the Afghan market, the LCOE for large-scale PV plants in Afghanistan with a 25-year warranty period was calculated.

Table 1- Estimation of LCOE, grid-connected and off-grid solar system in Afghanistan

LE	The cost of a grid-connected solar PV system	The cost of the off-grid solar PV system
0.05 kWh	864 $ kWp	1344 $ kWp

The calculation of the average cost of electricity generation by source in Afghanistan, considering the average price of various sources in 2019, revealed that solar PV is the second cheapest form of energy generation after onshore wind. (Figure 4.)

The cost of the PV system, custom taxes, transportation, availability of systems, fees of installing power plants, and rooftop PV were all considered in the economic analysis of PV expenditures in Afghanistan. The market was dominated by cheap and widely accessible Chinese and Indian PV systems. Aside from that, the cost of installation, transportation, and maintenance is inexpensive. The cost of building and operating a conventional PV power plant in Afghanistan has been assessed at $0.05 per kWh, demonstrating justified investment capacity with future cash flows.

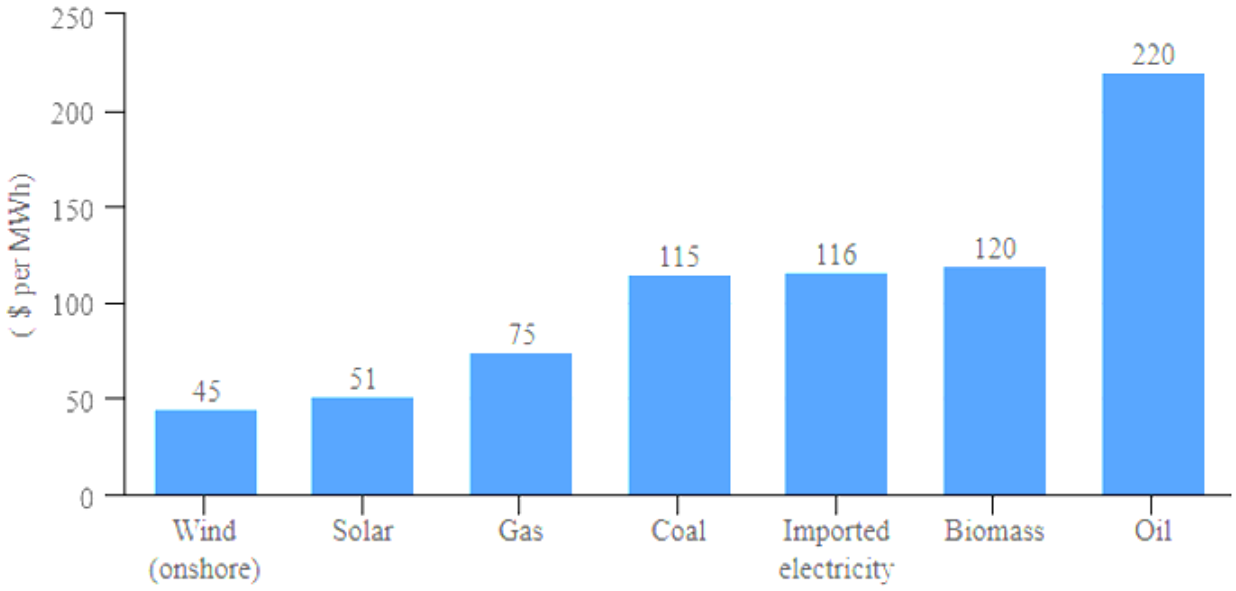


Figure 4. The average cost of electricity by the source in Afghanistan (Source: Ahmad Tamim Mehrad, 2021)

Afghanistan's solar energy market has seen two major trends over the last decade. The first is the growing trend of solar energy production, particularly rooftop PV, and the second is the ongoing cost reduction.

Furthermore, air pollution and environmental issues related to biomass energy consumption have imposed high costs on the government and, as a result, the Afghan people. Because solar PV is clean and cost-competitive in Afghanistan, where electricity generation is dominated by polluting diesel, thermal generators, and high tariffs, the use of renewable energy, particularly solar energy, can benefit the country's economy and the environment.

Although solar power generation is quite helpful for Afghanistan, it also has some economic barriers that have hampered the development of this technology. The following are the primary barriers:

- Solar energy projects require high capital investment and a long time forcashback.
- There is limited government support and subsidies for solar projects.
- Banks in Afghanistan are not interested in supporting big projects.
- There are financial risks associated with the performance of solar energy projects.

3. BARRIERS TO SOLAR ENERGY DEVELOPMENT

3.1. Security and political barriers

Political instability undermines any data collecting effortsneeded for proper planning. It is difficult to access reliableinformation about the Afghanistan energy sector due tothe lack of cooperation culture and current data storing andsharing facilities. Alternatively, most available informationis sketchy, anecdotal, piecemeal, and often conflicting[18]. Also, post-conflicts, provincial warlords, insurgentgroups, and the weak central government challengesany diplomatic relationships that could help addressthe nation’s energy demands.

3.2. Technical barriers and shortage of field professionals

While a national electric grid exists, it does not cover allparts of the country. Most southern and central areas ofthe nation do not have access to the grid. Other grid sectionshave limited capacities, making meeting voltageand frequency mismatches challenging to integrate newrenewable resources. However,there is no updated and inclusiveinformation about energy sector technical and financiallosses; the powernetwork losses were reported near40%, with an average annual loss of 2 million (USD)[19]. The lack of a central data monitoring system to measurenational demand prevents investment in sustainableenergy projects. Afghanistan also lacks technical expertsand energy workers experienced in clean energy.The country still suffers from high unemployment whileforeign-born workers are involved in large energy projects.

3.3. Economic barrier

Though there have been improvements in life expectancy, literacy,and per capita income since 2001, the country suffersfrom poverty and is dependent on foreign aid. Most citizenslack access to electricity, clean water, health care, andjobs. Political instability, corruption, and subjective legalenforcement hinder future economic growth and donot promote a commitment to invest in the high initialcosts of addressing these issues. As tax revenue is collected in the more unstable Afghani, investments are made in dollars.TheAfghanistan Land Authority oversees land developmentonly has 30% of urban and 10% of rural propertyregistered [20].

Furthermore, the domestic bankingand investment infrastructure remain focused in the bigcities. Investment in solar energy projects carriesa financial risk that few investors are eager to accept.Micro financing processes also prevent investment insmall projects.

3.4. Legal and regulatory framework

Policies and regulations for rural electrification, renewableenergy, and developing agreements for internationalpower purchasing have been created. Still, the WorldBank reportsa lack of natural process or timeline forimplementation. The Renewable Energy Policy encouragesDe Afghanistan Breshna Sherkat (DABS) but does not mandate a purchasing scheme.Private-sector development is encouraged to supportthe building and expansion of mini-grids and off-grid projects,but a central strategic plan is still needed.

3.5. Poor community awareness

Educating the public on the benefits of solar energy– such as its potential socio-economic impact – is ineffectivein developing counties, including Afghanistan.

CONCLUSIONS AND RECOMMENDATIONS

Afghanistan can benefit from its high solar energyresourcesto progress toward the Sustainable DevelopmentGoals and SDG-7. Afghanistanmust overcome significant barriers to maximize these assets, as identified in this research.The following are suggestions.

- Build training and employment opportunities: Investingin education and training should build a domestic community of technical professionals who can createand manage the integration of solar energysources,develop new technologies, and upgrade theexisting power supply network. The current numberofvocational training facilities needs to be increasedand improved.
- Provide risk insurance for solar energy projects:The government should provide risk insurance to promotesolar energy projects throughout the country. This should motivate banks, investors, andmicro creditors to engage the public's interest in constructing these infrastructural improvements towardssustainable energy goals.
- Improve existing policies and enforce regulations: Making the right decision for the deployment cost effective solarenergy technologies, which requires viableapproaches and a profound technical, managerial, and interdisciplinaryknowledge and expertise to lead Afghanistantoward self-sufficiency. This objective canbe achieved by conducting exhaustive research toprovide amarket-based energy development frameworkand involves innovative measures, tools, andtechniques interms of strategic planning and policydevelopment [21].
- Offer incentives favoring solar energy: However,solar energy technologies' deployment cost is steadily decreased (i.e., the average price of solar panelsdropped about 60% since 2011 [22]), and the still high initialinvestment is a challenge. Because solar energy costs are higher thancurrent nonrenewable sources, market incentivesshould be offered to encourage switching to renewableenergy. Therefore, well-management of payback,cash flow, tax-in-tariffs, and other financial initiativesto promote public and private sectors for an activeengagement is necessary.
- Increase public awareness: Educating the importanceof solar energy should encourage the public to increaseits awareness and use within the energy grid.A lack of stakeholders and beneficiaries of energy projects'awareness of the potential long-term benefits of the investmentlifecycle is reported [23]. This problem, along with many others linked to improperdecision-making and inadequate

policy development.In which missing decision-making standardprocess and procedure (on time, and budget andrisks), external and internal factors evaluation (economic,political, behavioral, and cultural), interest tocontrol wholesale markets, etc., leads to instant responsesinstead of sustainable solutions [24]. Information and Communications Technology (ICT)is recommended for public awareness, information broadcasting, and, more importantly, local engagement [25].

At last, Afghanistan can potentially produce 222000 MW of solar power, sufficient to meet its domestic energydemand. However, deploying and integrati ngsolar energysourcesare challenging and require politicalcommitment,academic and technical studies, and astrong economy.

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